

8.0 SUMMARY AND CONCLUSIONS

The primary purpose of this study was to address environmental concerns raised by the potential for dredging sand from the OCS offshore the State of Alabama for beach replenishment. Primary concerns focused on physical and biological components of the environment at five proposed sand resource areas. Biological and physical processes data were collected and analyzed to assess the potential impacts of offshore dredging activities within the study area to minimize or preclude long-term adverse environmental impacts at potential borrow sites and along the coastline landward of resource sites. Furthermore, wave transformation and sediment transport numerical modeling were employed to simulate the physical environmental effects of proposed sand dredging operations to ensure that offshore sand resources are developed in an environmentally sound manner. Of the five potential sand resource areas, four were chosen for evaluating sand extraction scenarios based on discussions of beach replenishment needs with Geological Survey of Alabama personnel (Hummell, 1999). Area 5 at the western end of the study area was not evaluated as a sand borrow source because it is substantially removed from beach areas of greatest replenishment need and the sediment was least compatible with native beach sand (see Parker et al., 1997).

The following discussion provides a summary of results and conclusions regarding the potential environmental effects of sand mining on the OCS for replenishing sand to eroding beaches. Because benthic and pelagic biological characteristics are in part determined by spatially varying physical processes throughout the study area, physical processes analyses are summarized first.

8.1 WAVE TRANSFORMATION MODELING

A primary component of any physical environmental effects analysis related to sand mining from the OCS must include numerical wave transformation modeling. Potentially rapid and significant changes in bathymetry due to sand extraction from the OCS may have substantial impact on wave propagation patterns on the continental shelf and at the shoreline. In turn, sediment transport patterns may be altered so as to adversely impact erosion problems being mitigated. As such, substantial effort was spent understanding existing wave propagation patterns relative to those resulting from potential sand extraction scenarios.

The spectral wave transformation model REF/DIF S was used to evaluate changes in wave approach resulting from potential sand dredging activities. REF/DIF S is a combined refraction and diffraction spectral wave model, which can simulate the behavior of a random sea and incorporates the effects of shoaling, wave breaking, refraction, diffraction, and energy dissipation. A spectral wave model was selected to simulate wave transformation because of its ability to propagate realistic wave components (a spectrum) simultaneously across the continental shelf surface. By simulating several wave components together, a spectral wave model represents nature more closely.

Accuracy of the wave transformation model is affected by the quality of selected input data and parameters. The spectral wave modeling approach requires the development of precise spectrum in the energy and directional domain. USACE WIS data and NOAA buoy data were used to derive input wave conditions. The Gulf of Mexico experiences minimal variation in wave climate, and with the exception of storm events, typical conditions are directionally narrow and energetically mild.

From the available data, prevalent seasonal conditions were used to generate accurate seasonal wave climates through development of combined directional/energy spectra. Seasonal wave conditions were selected to represent the differences in spectral wave approach and to investigate long-term average trends in wave and sediment transport patterns (nearshore and

offshore). Input spectra (rather than specific directions and/or frequencies) were represented through empirical approximations and verified through comparison to observed wave data. In this manner, actual conditions are simulated rather than using approximations of the frequency and directional spectra based on primary wave periods and directions. In addition, an extreme storm event (50-yr storm) was developed to investigate potential impacts during high energy conditions.

Wave transformation results identify key areas of wave convergence, wave divergence, and shadow zones offshore Alabama. For seasonal simulations, significant wave heights and wave angles experience little variation to the 15-m depth contour where the wave field begins to feel the influence of bathymetry. Seaward of Dauphin Island, wave heights are relatively consistent along the shoreline while the eastern end of the island is protected from significant wave energy by a shadow zone produced from Pelican Island (subaerial portion of the ebb-tidal delta) and subaqueous shoals associated with the ebb delta. Several areas of wave convergence were identified from the Dauphin Island simulations, including those associated with the Mobile Outer Mound disposal site, which focuses wave energy near Pelican Island during most seasons. Wave focusing caused by Mobile Outer Mound most likely results in an unnatural increase in the erosion rate at Pelican Island, and during a storm event may significantly erode the protective island. Areas of wave convergence and divergence along Morgan Peninsula are primarily caused by southwest-oriented shoals on the continental shelf. For the 50-yr storm simulation, wave patterns are similar to normal seasonal results. An increase in wave height is significant in many areas where wave convergence occurs. For example, the Mobile Outer Mound disposal site concentrates 4.0- to 4.5-m storm wave heights on Pelican Island.

Wave height results also were compared with historical shoreline change rates for Dauphin Island and Morgan Peninsula. Approaching wave heights under existing conditions correlate relatively well to historical erosion/accretion rates. Along most stretches of coastline, areas of high waves correspond to historical shoreline retreat, while reduced wave energy corresponds to areas that are historically stable or accreting. The correlation provides an increased level of confidence in the wave modeling results.

Similar results (as those shown for existing conditions) were illustrated for post-dredging simulations to investigate the potential physical environmental impacts to the propagating wave field. Differences in wave propagation are difficult to visualize, so quantitative wave height comparisons were made between pre- and post-dredging simulations. At Dauphin Island, maximum wave height differences (both reduction and augmentation) for seasonal simulations ranged from ± 0.02 to 0.2 m. These maximum changes dissipate relatively rapidly as waves break and advance towards the coast. At Morgan Peninsula, maximum wave height differences were slightly larger (± 0.2 to 0.4 m) due to borrow site sizes and orientations, as well as their proximity to the shoreline. However, wave energy is dissipated as waves propagate toward the shoreline, and increases in wave height of 0.1 m or less are observed at the potential impact areas along the coast. Overall, the physical environmental impact caused by offshore sand extraction during seasonal simulations is minimal.

During extreme wave conditions (i.e., the 50-yr storm), wave heights are modified between ± 1.5 and 2.0 m, suggesting a rather significant change. For the sand resource site in Sand Resource Area 4, a significant amount of wave energy is dissipated before waves reach the coast. For example, wave height increases are less than 0.5 m along a majority of Pelican Island. Furthermore, under storm conditions, wave heights are substantially larger relative to normal wave conditions, regardless of modifications caused by the sand dredging. Therefore, a maximum change of 0.5 m may not significantly increase nearshore erosion above existing conditions near Dauphin Island.

Sand borrow sites within Sand Resource Areas 1, 2, and 3, which are located closer to the shoreline than Sand Resource Area 4, have a greater impact on the wave field. A smaller amount

of wave energy is dissipated before reaching the shoreline, and changes to wave heights are large enough to result in measured impacts at certain locations along Morgan Peninsula.

8.2 CIRCULATION AND SEDIMENT TRANSPORT DYNAMICS

Current measurements and analyses and wave transformation modeling provided baseline information on incident processes impacting coastal environments under existing conditions and with respect to proposed sand mining activities for beach replenishment. Ultimately, the most important data set for understanding physical processes impacts from offshore sand extraction is changes in sediment transport dynamics resulting from potential sand extraction scenarios relative to existing conditions.

Three independent sediment transport analyses were completed to evaluate impacts due to sand mining. First, historical sediment transport trends were quantified to document regional, long-term sediment movement throughout the study area using historical bathymetry data sets. Erosion and accretion patterns were documented, and sediment transport rates in the littoral zone and at offshore borrow sites were evaluated to assess potential changes due to offshore sand dredging activities. Second, sediment transport patterns at proposed offshore borrow sites were evaluated using wave modeling results and current measurements. Post-dredging wave model results were integrated with regional current measurements to estimate sediment transport trends for predicting borrow site infilling rates. Third, nearshore currents and sediment transport were modeled using wave modeling output to document potential impacts to the longshore sand transport system (beach erosion and accretion). All three methods were compared for evaluating consistency of measurements relative to predictions, and potential impacts were identified.

8.2.1 Historical Sediment Transport Patterns

Regional geomorphic changes between 1917/20 and 1982/91 were documented for assessing long-term, net coastal sediment transport dynamics. Although these data do not provide information on the potential impacts of sand dredging from proposed borrow sites, they do provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport.

A comparison of erosion and deposition volumes at proposed borrow sites provided a method for quantifying net sediment transport rates (or borrow site infilling rates). For borrow sites in Sand Resource Areas 1, 2, and 3, net transport rates ranged from about 9,000 to 34,000 m³/yr. This compared well with sediment transport predictions made near borrow sites using wave model output and currents measurements (13,000 to 43,000 m³/yr). For Sand Resource Area 4, net deposition at a rate of about 65,000 m³/yr recorded the influence of sediment input from Mobile Bay and local transport processes.

The net longshore sand transport rate for the Morgan Peninsula was determined by comparing cells of erosion and accretion in the littoral zone (seaward to 6-m depth contour [NGVD]) between Perdido Pass and Main Pass (Mobile Bay entrance) in a sediment budget formulation. The net transport rate for that portion of the study area was determined to be approximately 106,000 m³/yr to the west. Net transport rates determined via sediment transport modeling ranged from about 50,000 to 150,000 m³/yr. These rates compare well and provide a measured level of confidence in wave and sediment transport modeling predictions relative to impacts associated with sand dredging from proposed borrow sites.

8.2.2 Sediment Transport at Potential Borrow Sites

In addition to predicted modifications to the wave field, potential sand mining at offshore borrow sites results in minor changes to sediment transport pathways in and around the sites.

Modification to bathymetry caused by sand mining influences local hydrodynamic and sediment transport processes, but areas adjacent to the borrow site do not experience dramatic changes in wave and transport characteristics.

Initially, sediment transport at borrow sites will experience mild changes after sand dredging activities. For example, sediment entering the dredged area will settle and have difficulty exiting. After several years of seasonal and storm activity, sediment will be deposited at the borrow sites, eventually re-establishing pre-dredging conditions. Given the water depths at the proposed borrow sites, it is expected that minimal impacts will occur during sediment infilling of the borrow site. The pre- and post-dredging differences will be reduced as sediment infills the borrow site, and wave and resulting sediment transport patterns will steadily return to pre-dredging conditions.

Sediment that replaces the dredged material will fluctuate based on location, time of dredging, and storm characteristics following dredging episodes. Borrow sites at Sand Resource Areas 1, 2, and 3 are expected to fill with the same material that was excavated (the entire shelf surface south of the Morgan Peninsula is at least 95% medium-to-fine sand). The sediment type in this region is consistent, high-quality, and compatible for beach replenishment. The potential borrow site at Sand Resource Area 4, however, will likely be filled with fine sediment (i.e., fine sand to clay) exiting Mobile Bay by natural processes or human activities (maintenance channel dredging and disposal). Because the potential transport rate plus sediment flux from Mobile Bay is substantially greater than shelf transport rates alone, the borrow site in Sand Resource Area 4 will fill faster than other borrow sites, limiting the likelihood for multiple dredging events from the same area.

8.2.3 Nearshore Sediment Transport Modeling

For this study, the potential effects of offshore sand mining on nearshore sediment transport patterns are of interest, because dredged holes can intensify wave energy at the shoreline and create erosional hot-spots. Therefore, numerical techniques were developed to utilize the nearshore wave information derived from REF/DIF S to evaluate longshore sediment transport patterns. First, a wave-induced current model was developed to determine the magnitude and distribution of the surf zone current. Bathymetry, wave height, and radiation stress information from the wave modeling provided the site-specific data needed to compute wave-induced current patterns. The nearshore current distribution results then were incorporated into a longshore sediment transport model based on the wave energy dissipation rate in the surf zone (Bodge, 1986). This approach yielded net longshore sediment transport rates for existing conditions, as well as post-dredging scenarios.

Application of the REF/DIF S wave model, a wave-induced current model, and a longshore sediment transport model provided the basis for comparing existing conditions to post-dredging conditions with regards to coastal processes. Average annual sediment transport patterns for existing conditions, as well as post-dredging scenarios, were evaluated for the Morgan Peninsula and Dauphin Island sub-grids to determine whether offshore sand dredging would cause a significant effect on average littoral sand transport conditions. In addition, sediment transport effects were evaluated for the 50-yr storm event. Extremal conditions indicate “worst-case” scenarios, where potential impacts of dredging are amplified in the predicted longshore sediment transport rates.

Sand dredging impacts for Sand Resource Areas 1, 2, and 3 illustrate that there is a defined, but somewhat minor, change in littoral transport. Due to naturally higher transport rates at the eastern end of coastal Alabama, the magnitude of impacts associated with Sand Resource Areas 1 and 2 appear to be higher than those associated with Sand Resource Area 3; however, the net transport rate landward of Sand Resource Area 3 is significantly lower than the rate associated with Sand Resource Areas 1 and 2. For all three sand resource sites, the maximum variation in annual littoral transport rate, along the beach landward of the site, is approximately 8% to 10% of the

existing value. In general, the increase or decrease in longshore sediment transport rates associated with each potential sand resource area amounts to approximately 1% to 2% of the net littoral drift, distributed over an approximate 10 km stretch of shoreline.

The potential impacts of dredging Sand Resource Area 4 on littoral transport rates are insignificant in relation to Sand Resource Areas 1, 2, and 3. Average annual conditions indicate a relatively high percentage change in transport rates along the eastern portion of Dauphin Island; however, the existing net littoral drift is almost non-existent at this location. The net effect of dredging Sand Resource Area 4 would direct a greater percentage of littoral sand transport to the east, with a maximum increase of approximately 8,000 m³/yr.

8.3 BENTHIC ENVIRONMENT

Results of the biological field surveys in the five sand resource areas agreed well with previous descriptions of benthic assemblages residing in shallow waters off the Alabama coast. Benthic assemblages surveyed in the five sand resource areas consisted of members of the major invertebrate and vertebrate groups that are commonly found in the study region. Numerically dominant infaunal groups included numerous crustaceans, echinoderms, molluscs, and polychaetous annelids, while epifaunal invertebrate taxa consisted primarily of sea stars, squid, and various shrimps. Fishes such as Atlantic croaker (*Micropogonius undulatus*), longspine porgy (*Stenotomus caprinus*), silver seatrout (*Cynoscion nothus*), and spot (*Leiostomus xanthurus*) were numerical dominants during the 1997 surveys and these species consistently are among the most ubiquitous and abundant demersal taxa in the region.

Seasonality was apparent from the biological field surveys. Infaunal abundance was substantially higher during the May survey than was observed in December. Nearly half of the infaunal taxa sampled over the entire project were found in both the May and December surveys; however, most (70%) of the remaining taxa were collected only during the May cruise, resulting in higher mean values of species richness compared to the December survey. Within season, sedimentary regime most affected infaunal assemblages. Sediment in the easternmost areas (Areas 1, 2, and 3) was predominantly sand as compared to the western sand resource areas (Areas 4 and 5) which were a mixture of sand and mud at most stations. Spatial differences in community composition were obvious. The eastern areas tended to support assemblages numerically dominated by the gastropod *Caecum* spp. and included many arthropods, bivalves, and gastropods, while the western areas supported assemblages that tended to be dominated by polychaetes in terms of abundance and species richness. The *Caecum*-associated assemblages of the eastern areas apparently are restricted to the more stable environmental characteristics of those sand sediment areas, whereas the western areas support assemblages numerically dominated by those taxa capable of exploiting the fluctuating, riverine-influenced habitats nearer Mobile Bay.

Trawl catches of epifauna and demersal ichthyofauna from Areas 1 and 2 yielded the fewest taxa and individuals during both the May and December surveys, while Areas 3, 4, and 5 yielded the most individuals and taxa. The composition of demersal assemblages across the Alabama sand resource areas is influenced by fluctuating hydrographic parameters in the western areas relative to the more stable eastern areas.

Potential benthic effects from dredging will result from sediment removal, suspension/dispersion, and deposition. Potential effects are expected to be short-term and localized. Seasonality and recruitment patterns indicate that removal of sand between late fall and early spring would result in less stress on benthic populations. Early-stage succession will begin within days of sand removal, through settlement of larval recruits, primarily annelids and bivalves. Initial larval recruitment will be dominated by the opportunistic taxa that were numerical dominants

in the western sand resource areas during the biological surveys (e.g., *Magelona* sp. H, *Mediomastus* spp., and *Paraprionospio pinnata*). These species are well adapted to environmental stress and exploit suitable habitat (especially fine-grained sediments) when it becomes available. Later successional stages of benthic recolonization will be more gradual, involving taxa that generally are less opportunistic and longer lived. Immigration of motile crustaceans, annelids, and echinoderms into impacted areas also will begin soon after excavation.

Recolonization of Areas 1, 2, and 3 east of Mobile Bay likely will occur in a timely manner and without persistent inhabitation by transitional assemblages. Infaunal assemblages that typically inhabit the eastern portion of the study area will most likely become reestablished within 2 years. Area 4 infaunal assemblages can be expected to recover more quickly than those in the eastern areas. Because of the physical environmental characteristics of Area 4, especially outflow of fresh water and fine sediment (silts and organics) from Mobile Bay, existing assemblages are comprised of species that colonize perturbed habitats. Infaunal assemblages that inhabit the western study areas would therefore become reestablished relatively rapidly, probably within 12 to 18 months. Given that the expected beach replenishment interval is on the order of a decade, and that the expected recovery time of the affected benthic community after sand removal is anticipated to be much less than that, the potential for significant cumulative benthic impacts is remote.

8.4 PELAGIC ENVIRONMENT

Based on existing information, potential effects from offshore dredging could occur to transitory pelagic species. Dredging effects on most zooplankton from entrainment and turbidity should be minimal due to high spatial and temporal variability of the populations. If Area 4 is used as a sand source, an environmental window excluding summer and fall months could be considered to avoid dredging when shrimp and blue crab larvae are most prevalent, but only if additional data become available to determine the extent of impacts and justify the restriction. Dredging is unlikely to significantly affect squid populations in the vicinity of the sand resource areas. Although entrainment, attraction, and turbidity could occur from dredging, quantitative data are lacking to support the use of an environmental window for pelagic fishes.

The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head. No significant effects on turtles are expected from turbidity, anoxia, or noise. Loggerheads are expected to be the most abundant turtle in the project area. Increased loggerhead densities may be expected during the nesting season, which extends from 1 May through 30 November. A schedule that avoids the loggerhead nesting season also would avoid potential impacts to occasional nesting green and leatherback turtles. Hawksbill and Kemp's Ridley turtles do not nest anywhere near the project area. It is not known whether sea turtles are likely to be brumating in bottom sediments of the project area during winter. Consequently, there is insufficient information to determine whether seasonal restrictions on dredging during winter months would be appropriate.

The two marine mammals most likely to be found in and near the project area are the Atlantic spotted dolphin and the bottlenose dolphin. There is no strong seasonal pattern in abundance for either species that would provide an appropriate basis for seasonal restrictions on the project. In addition, the likelihood of significant impact from physical injury, turbidity, or noise is low even if these animals are present.

Zooplankton, squids, fishes, sea turtles, and marine mammals were groups in the pelagic environment considered to be potentially affected by offshore dredging. No cumulative effects to any of these pelagic groups are expected from multiple sand mining operations.

8.5 SYNTHESIS

The data collected, analyses performed, and simulations conducted for this study indicate that proposed sand dredging at sites evaluated on the OCS should have minimal environmental impact on fluid and sediment dynamics and biological communities. Short-term impacts to benthic communities are expected due to the physical removal of borrow material, but the potential for significant cumulative benthic impacts is remote. Additionally, no cumulative effects to any of the pelagic groups are expected from potential sand mining operations.

Minimal physical environmental impacts due to potential sand dredging operations have been identified through wave and sediment transport simulations. However, under normal wave conditions, the maximum change in sand transport dynamics is about 5% of existing conditions. Because wave and sediment transport predictions are only reliable to within about $\pm 25\%$, predicted changes are not deemed significant. Although changes during storm conditions illustrate greater variation, the ability of models to predict storm wave transformation and resultant sediment transport is less certain. Because minimal impacts were documented to wave and sediment transport dynamics and biology, particularly along the eastern portion of the study area, additional data may be required for a specific sand extraction scenario to determine the extent of impacts.